



Fadiga

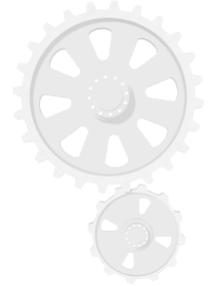
Elementos de Maquinas 1

Prof. Alan Dantas

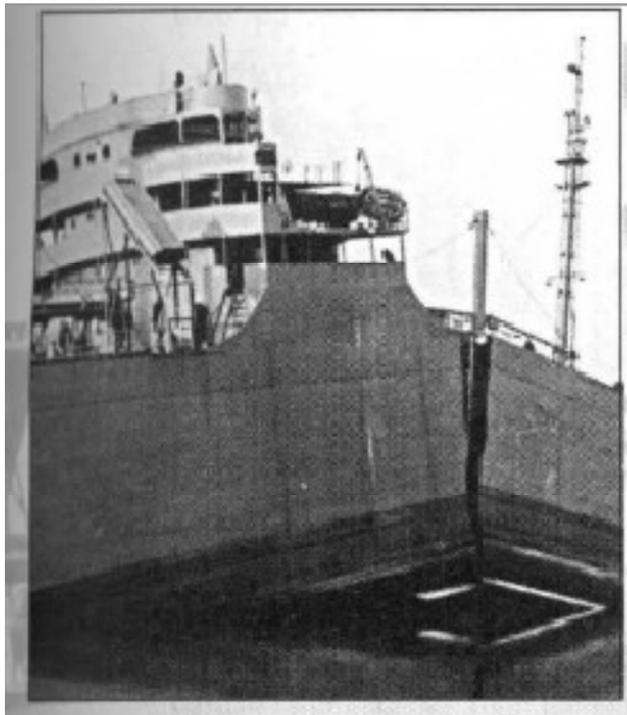
*Colegiado de
Engenharia Mecânica*



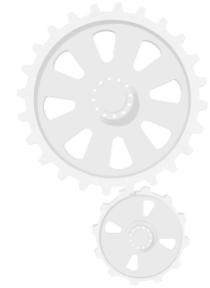
Falhas por fadiga



- Provocam fratura devido a carga cíclica
- A falha tende a ocorrer a um limite bem mais baixo que o de escoamento

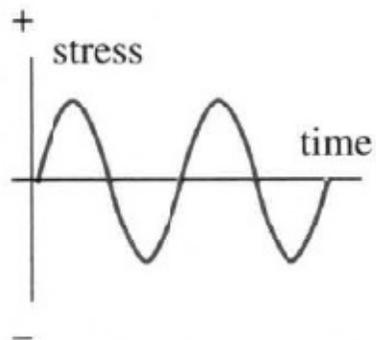


Falha por fadiga



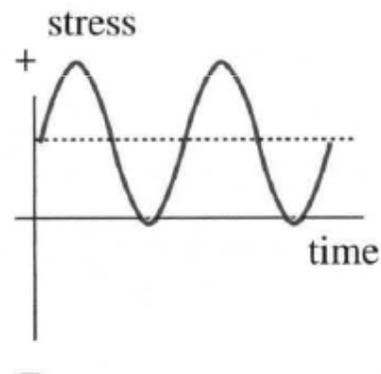
- Variação da tensão com o tempo

Alternada



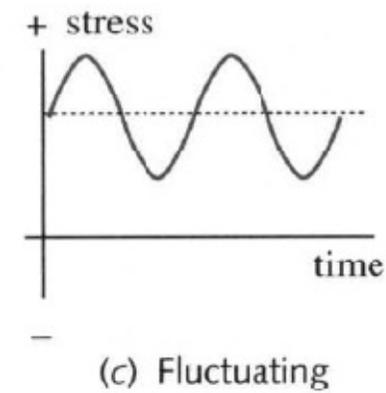
(a) Fully reversed

Repetida



(b) Repeated

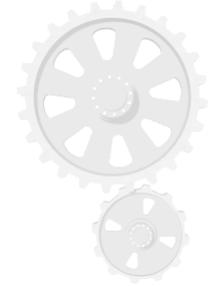
Flutuante



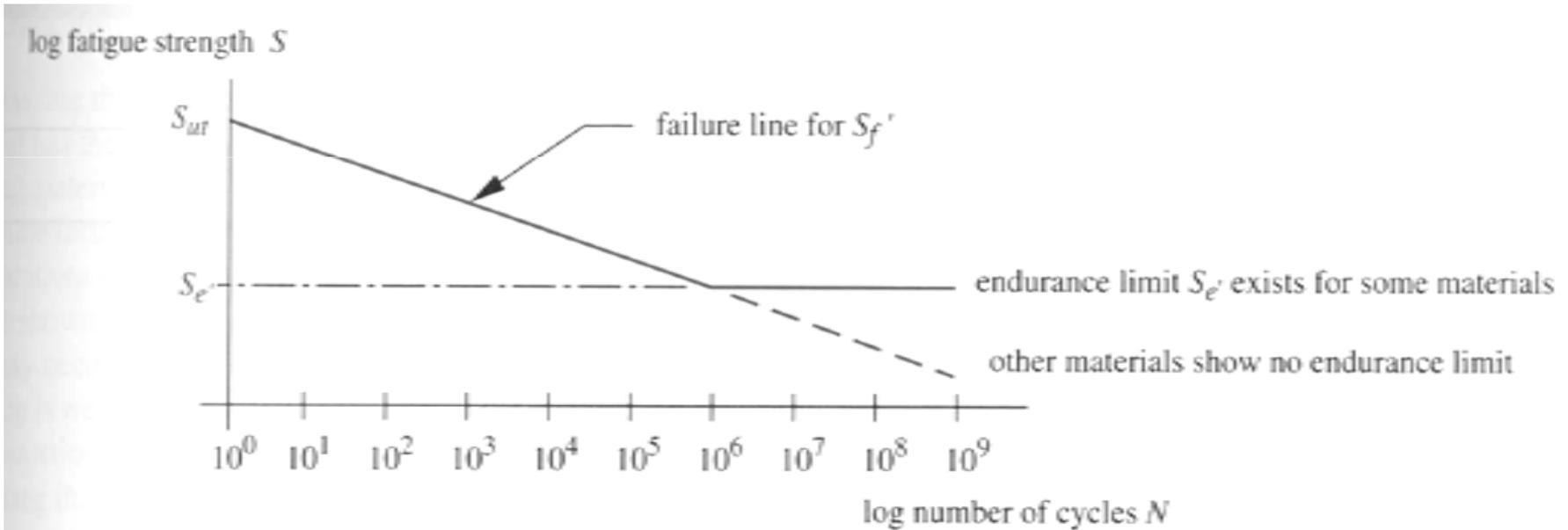
(c) Fluctuating



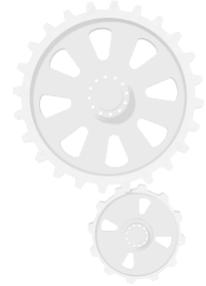
Falha por fadiga



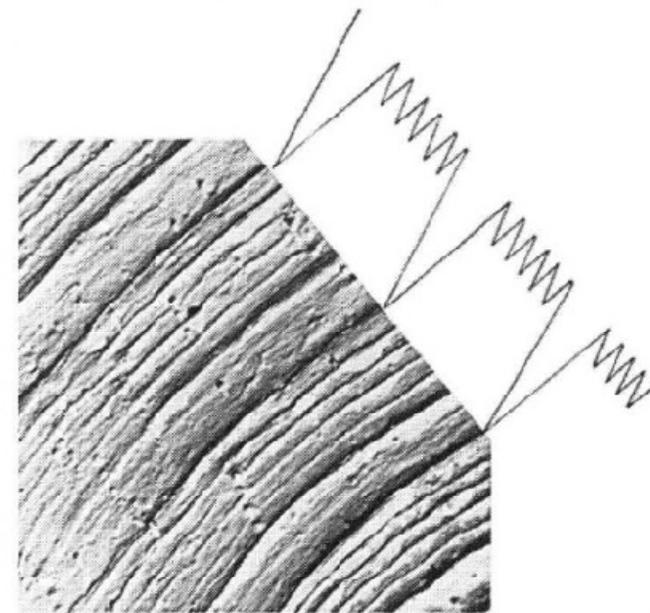
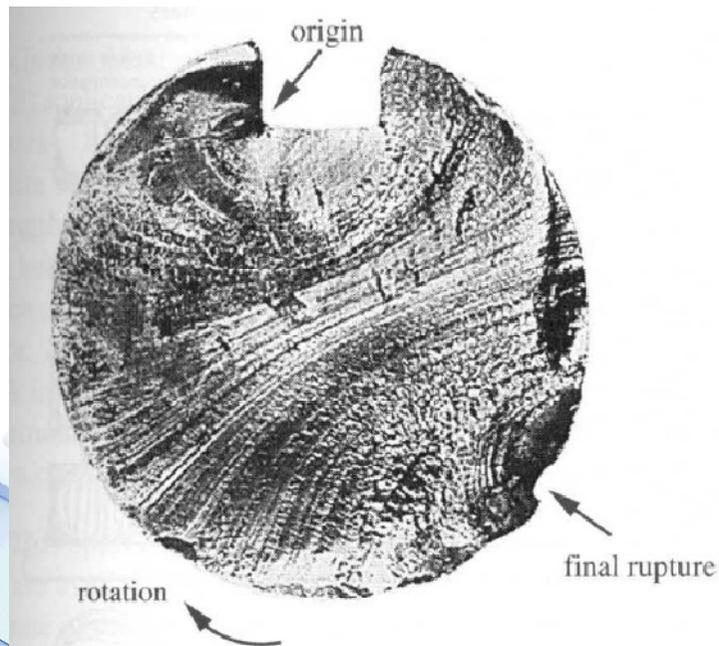
- Diagrama S-N



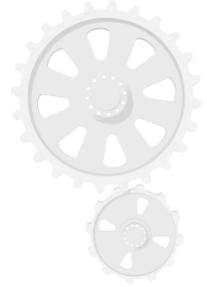
Estágios da falha por fadiga



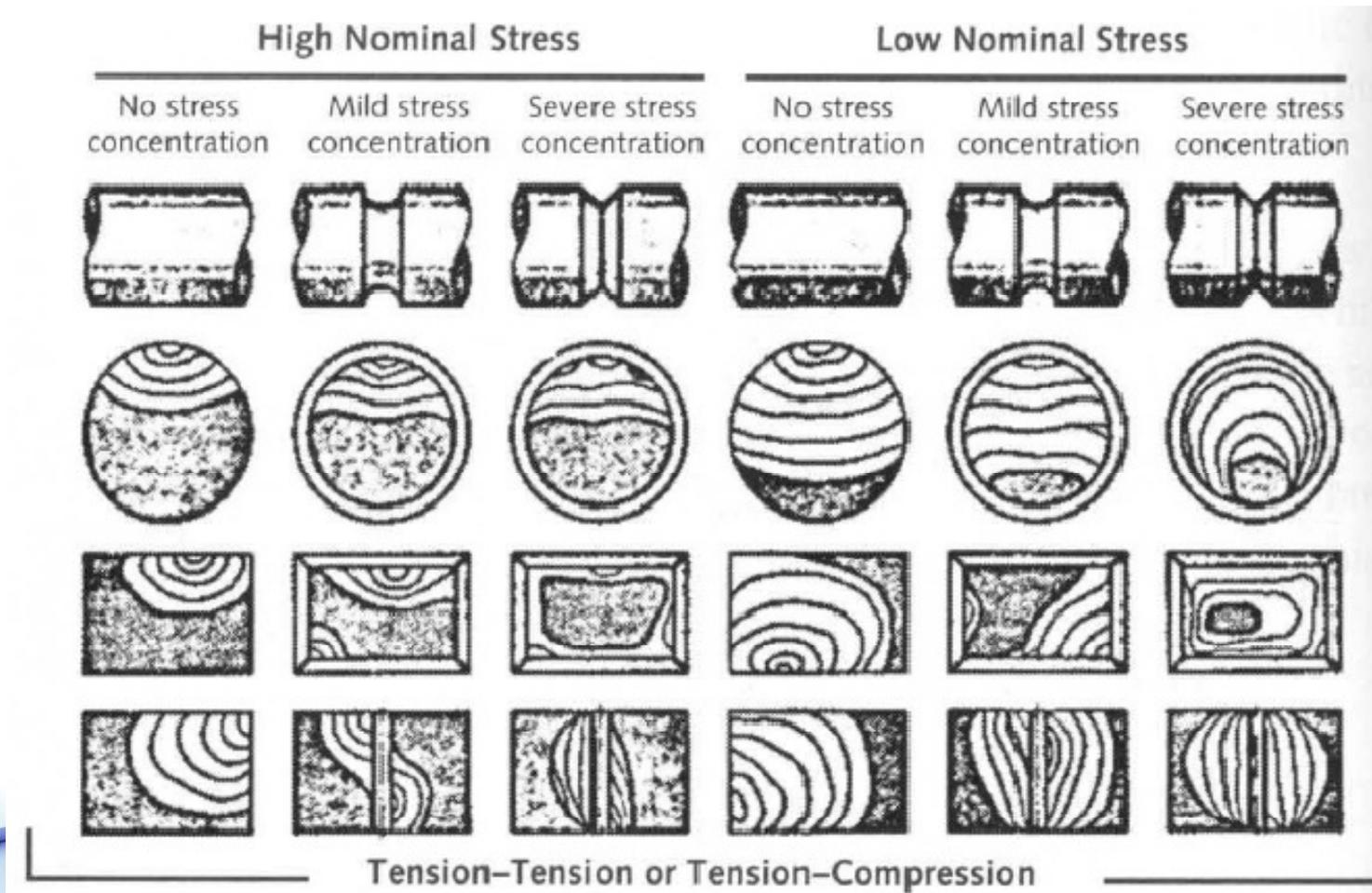
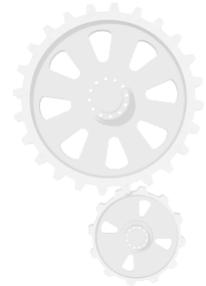
- Início da Trinca
- Propagação da Trinca
- Fratura



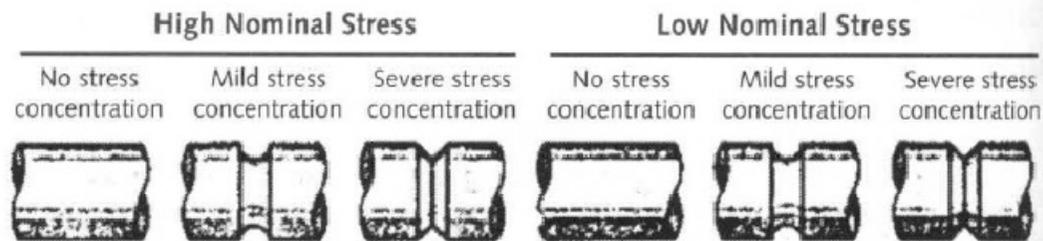
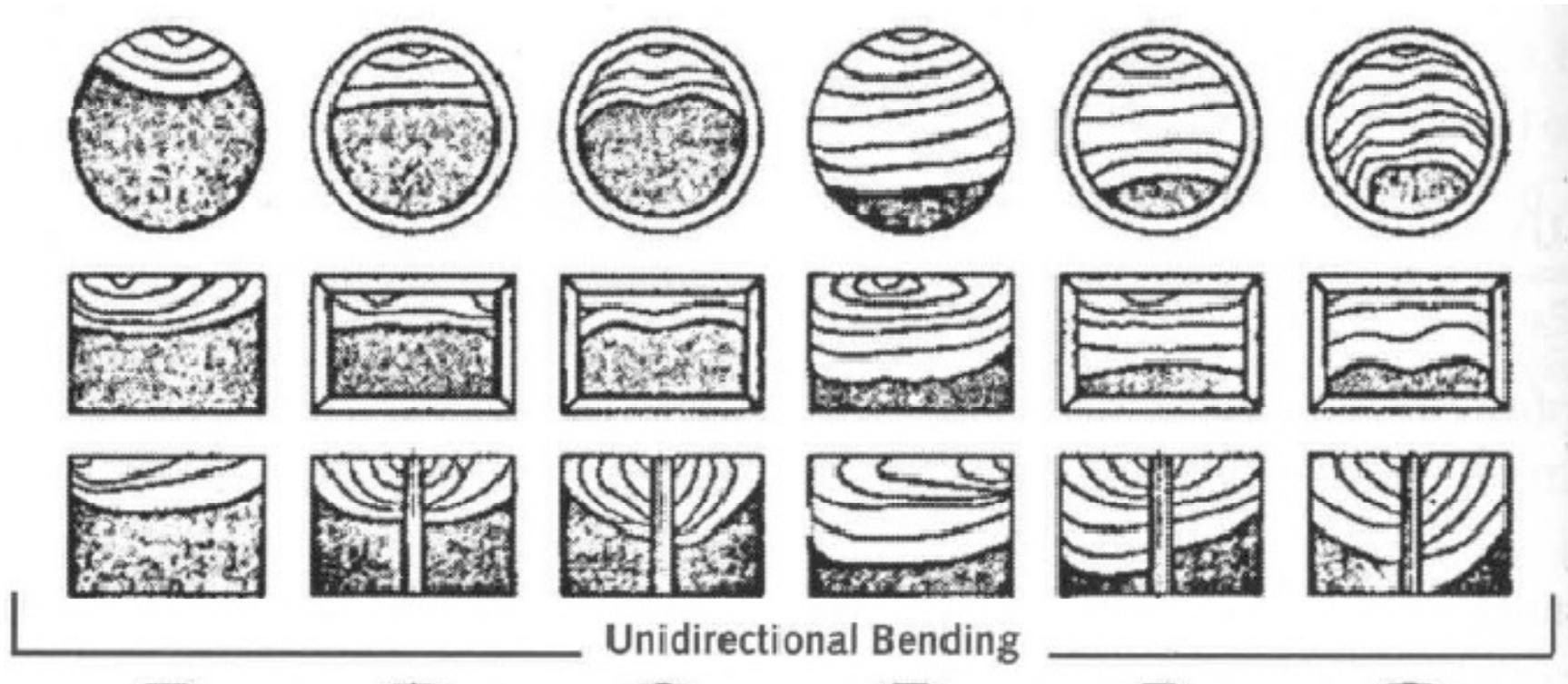
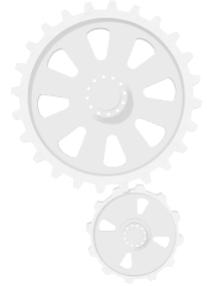
Exemplo



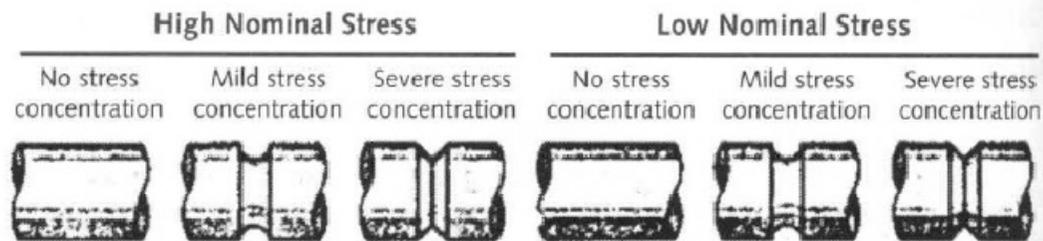
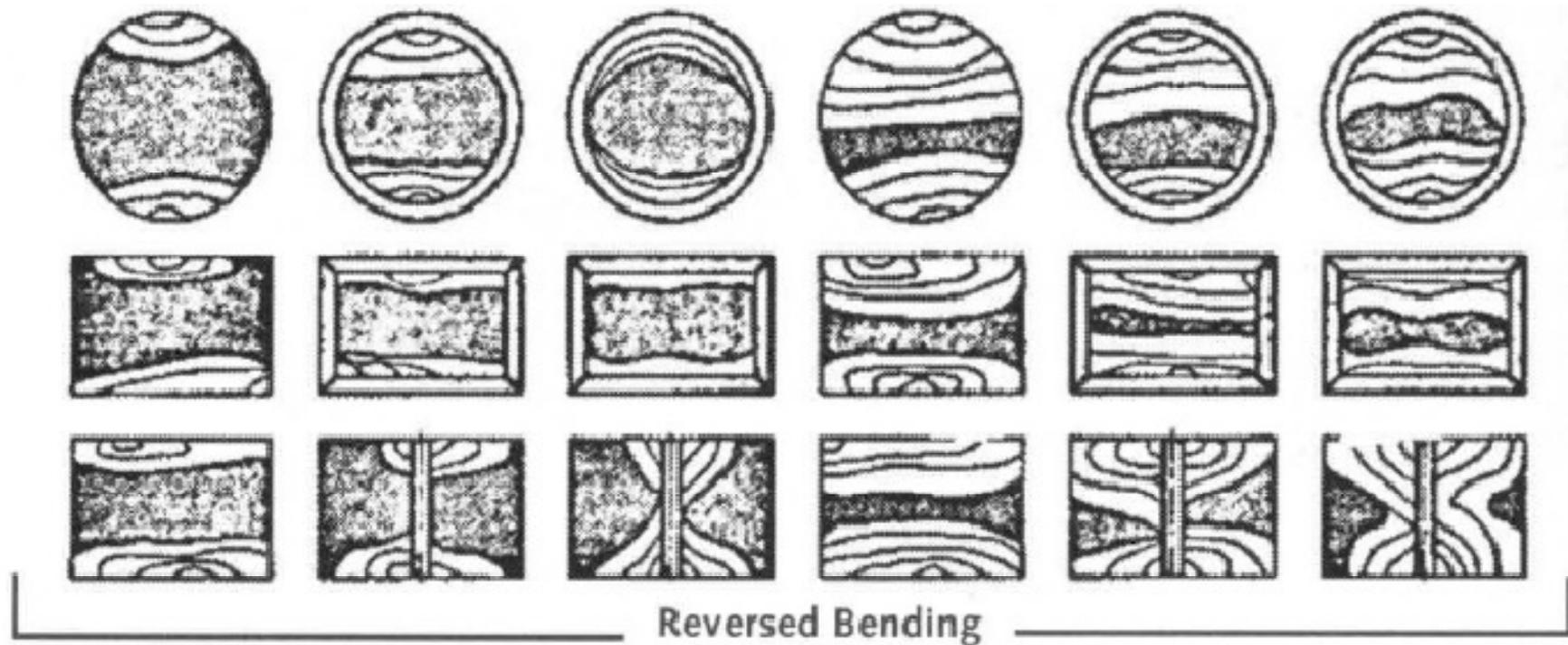
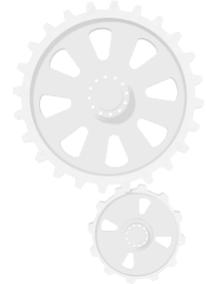
Morfologia da Fratura



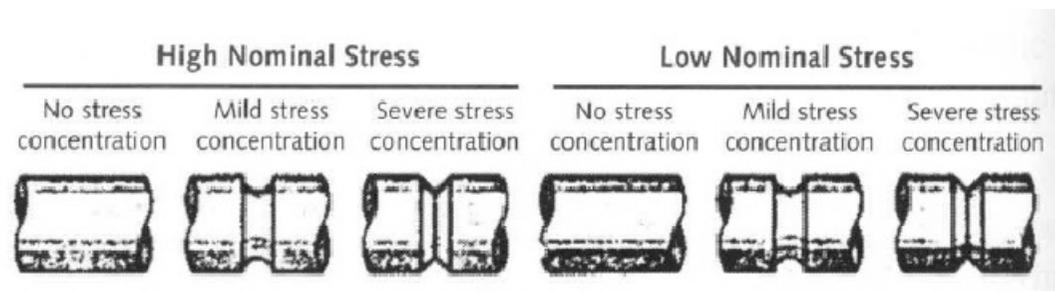
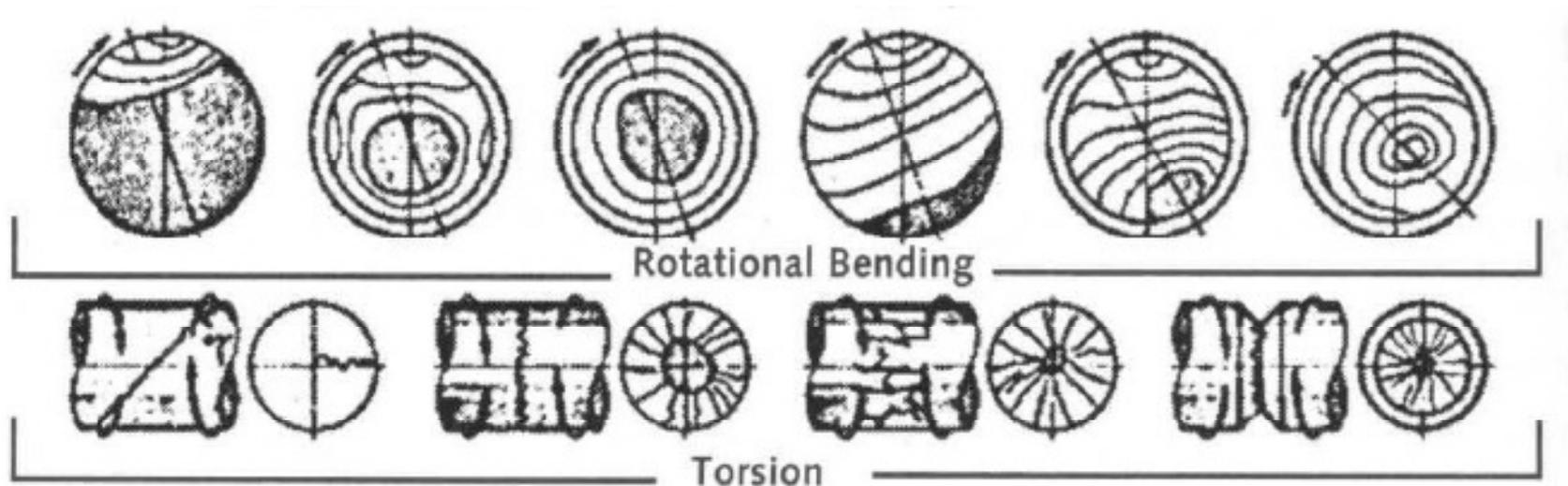
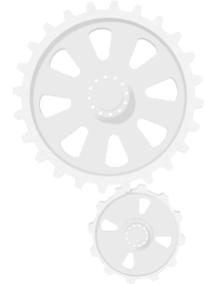
Morfologia da Fratura



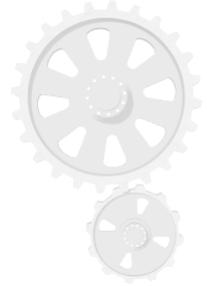
Morfologia da fratura



Morfologia da Fratura



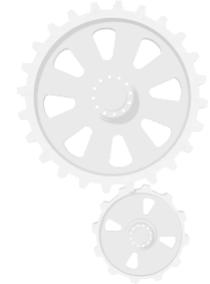
Modelos de Falha por fadiga



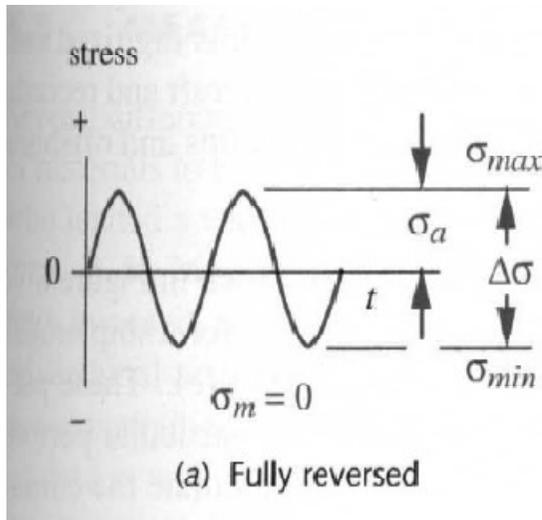
- Definição dos regimes de fadiga
 - Fadiga de baixo ciclo (FBC)
 - Fadiga de alto ciclo (FAC)
- Tensão x nº Ciclos ($S-N$)
- Deformação x nº Ciclos ($\varepsilon-N$)
- Mecânica da Fratura Linear Elástica (MFLE)



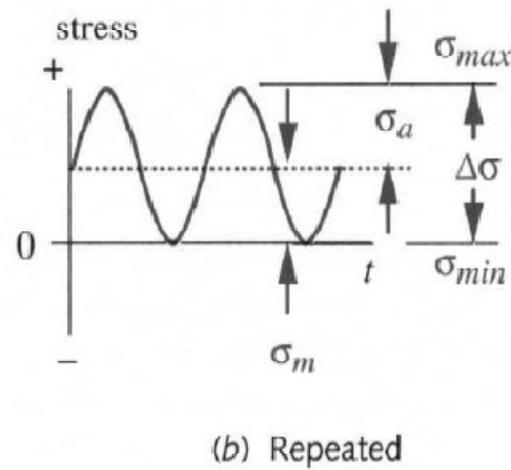
Cargas de Fadiga



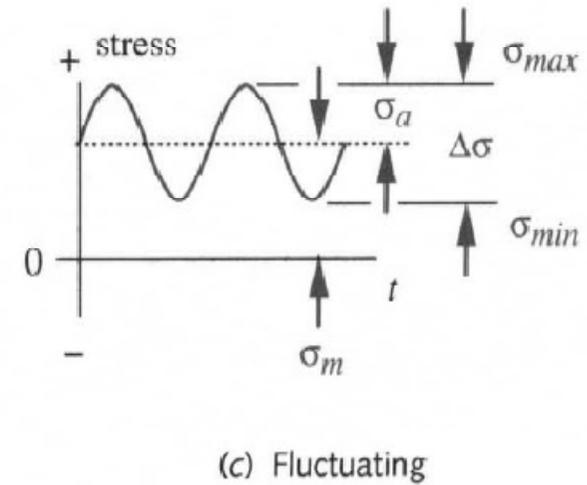
Alternada



Repetida



Flutuante



$$\Delta\sigma = \sigma_{max} - \sigma_{min}$$

$$\sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2}$$

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2}$$

$$R = \frac{\sigma_{min}}{\sigma_{max}}$$

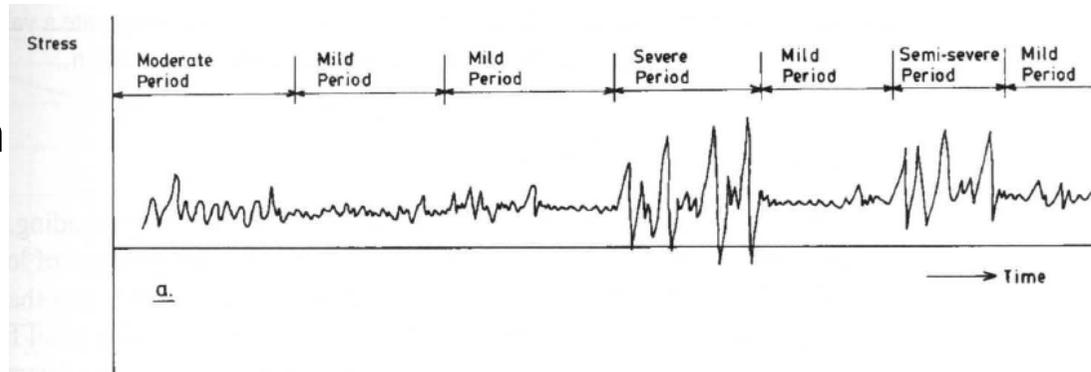
$$A = \frac{\sigma_a}{\sigma_m}$$



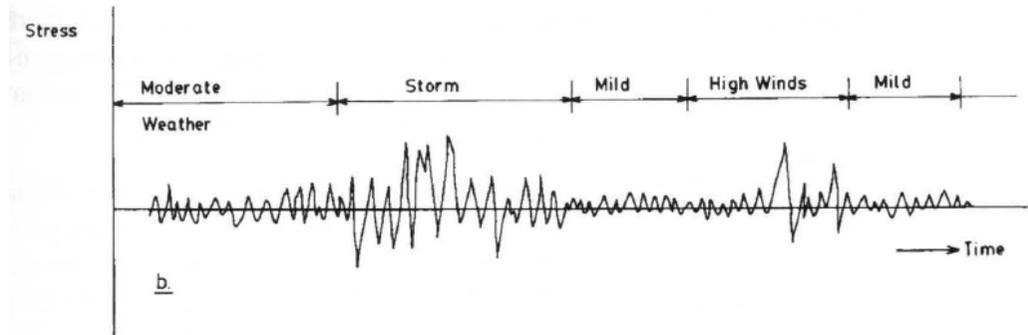
Carregamentos reais de serviço



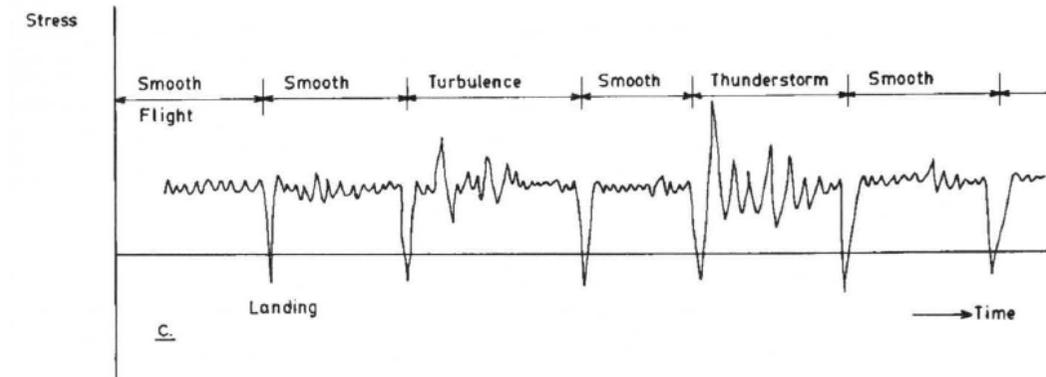
- Estrutura Genérica



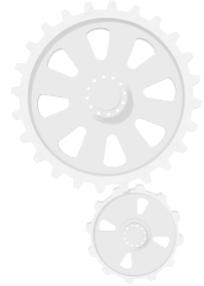
- Estrutura marítima



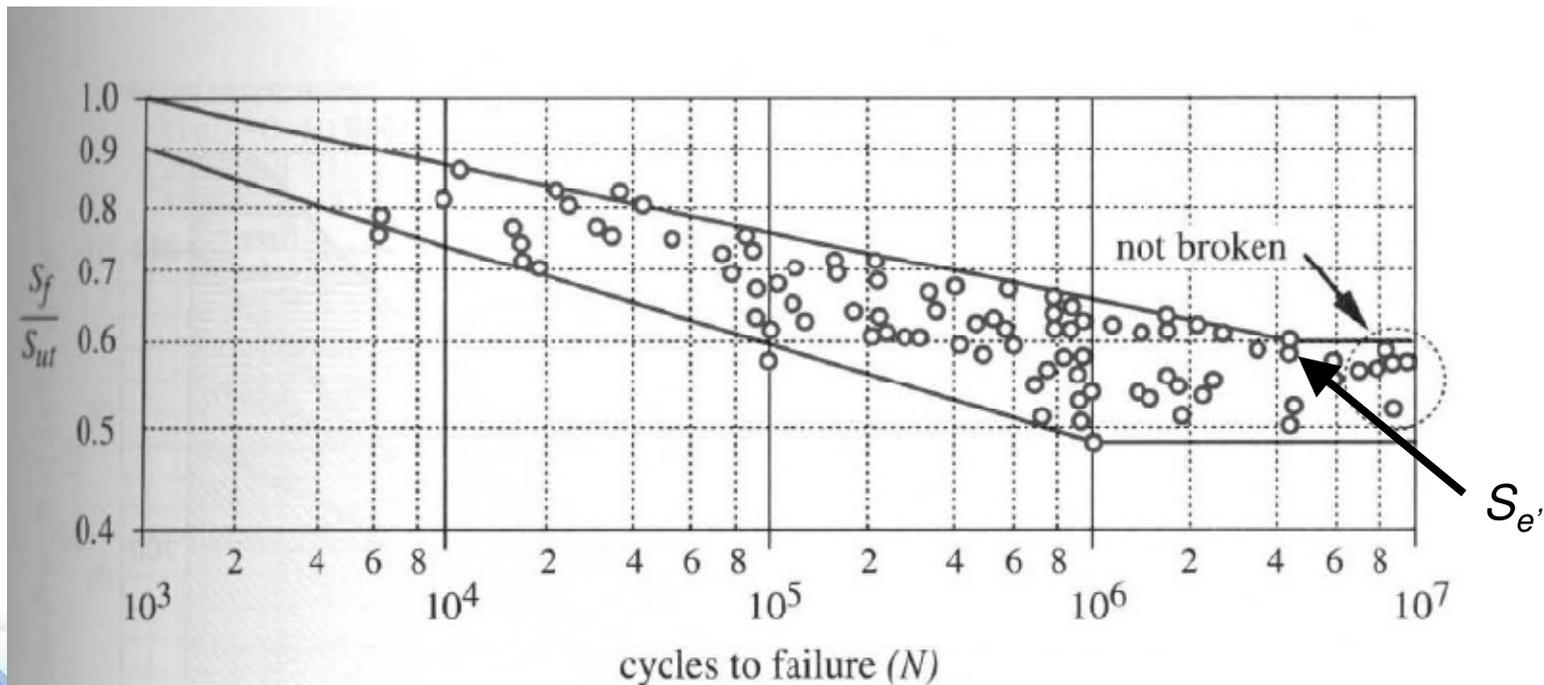
- Avião comercial



Critérios de medição de falha por fadiga



- Curva S-N no ensaio de flexão rotativa



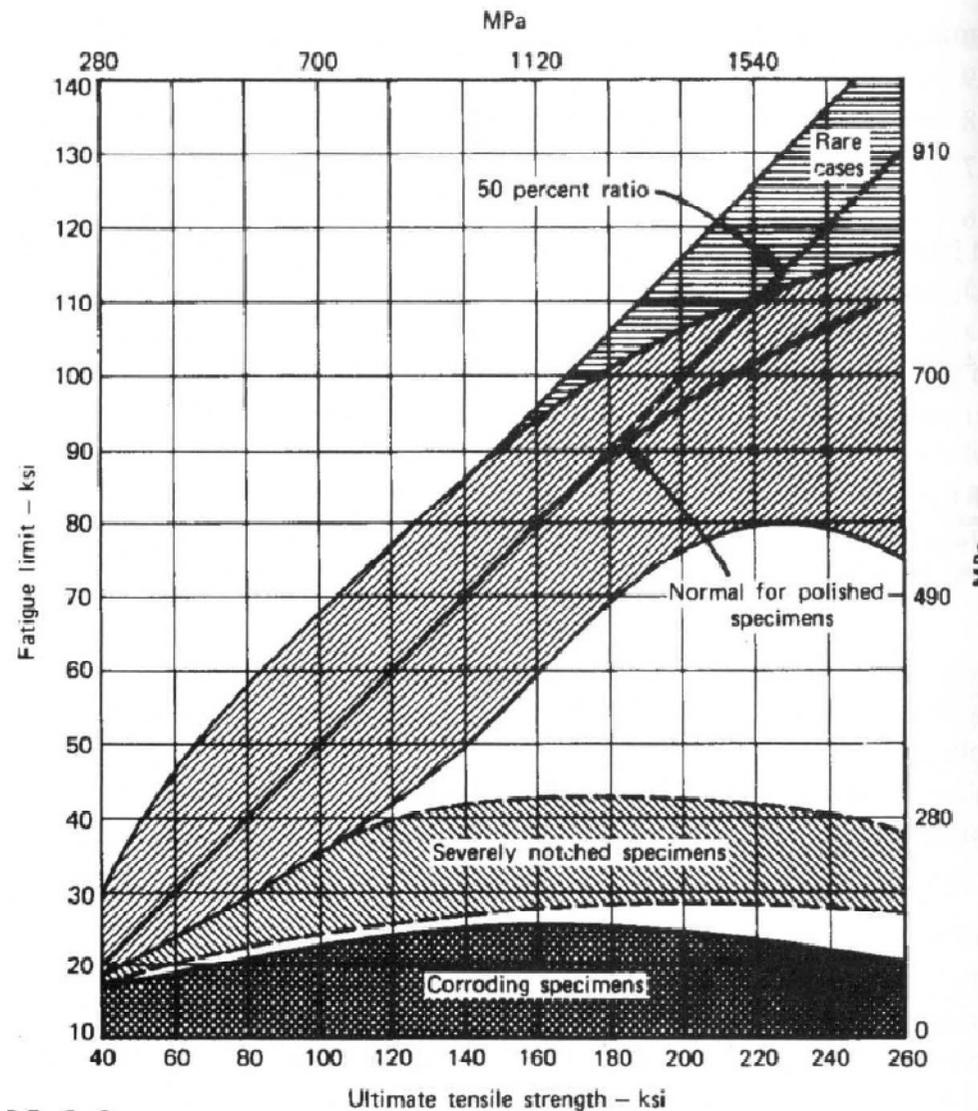
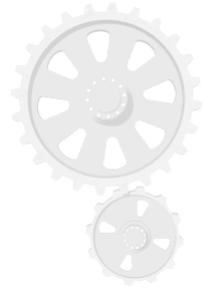
for steels :

$$S_{e'} \cong 0.5 S_{ut}$$

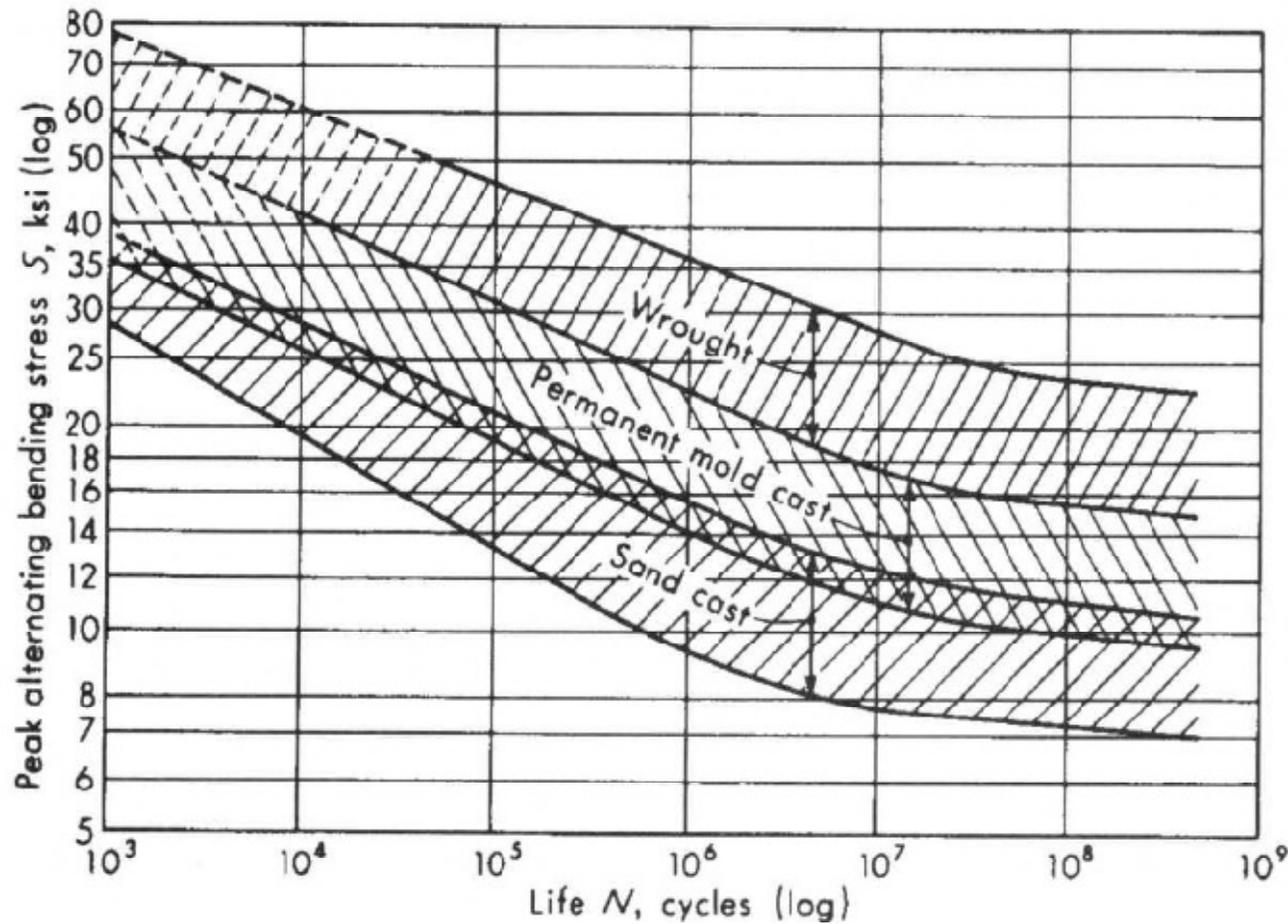
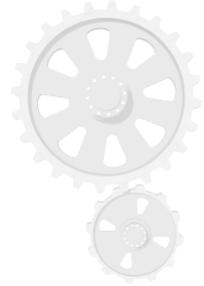
$$S_{ut} < 200 \text{ ksi}$$



Relação entre o limite de fadiga e resistência a tração

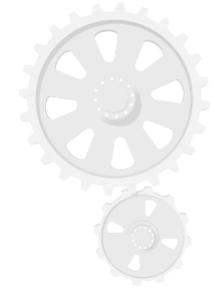


Curva S-N com S_e não definido



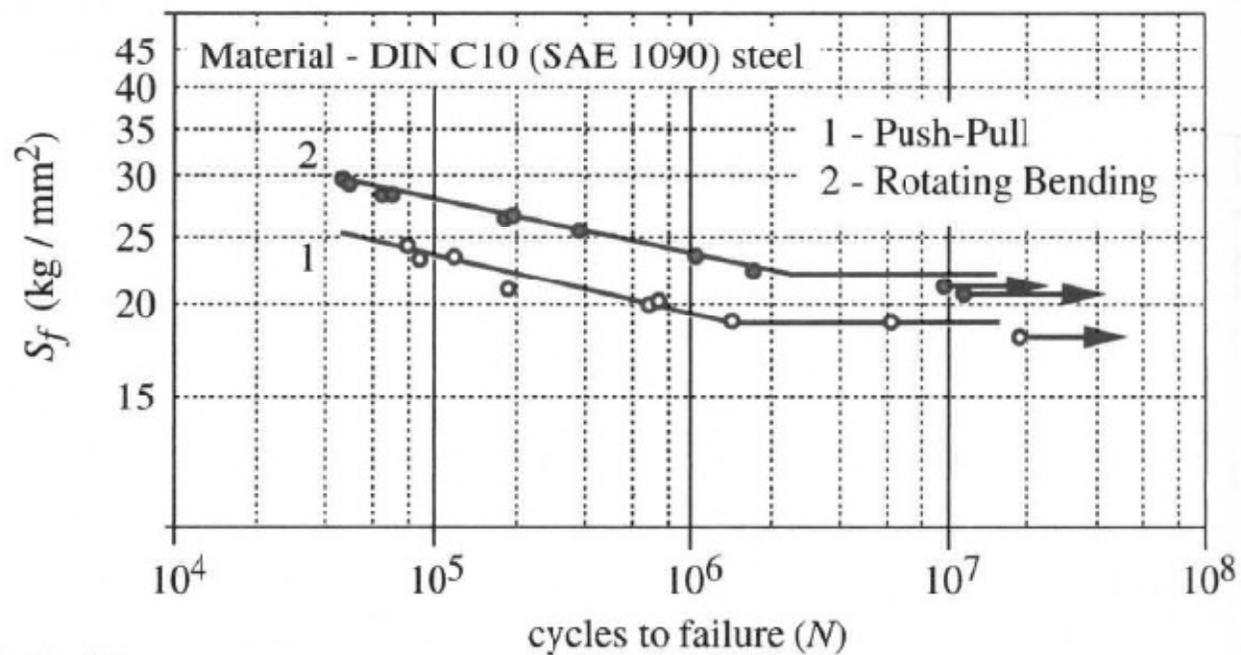
Resistência a Fadiga: S_f → para um N determinado

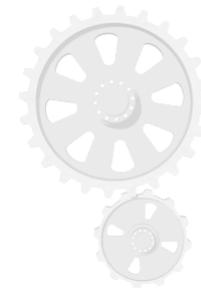




Determinação de S_e' e S_f'

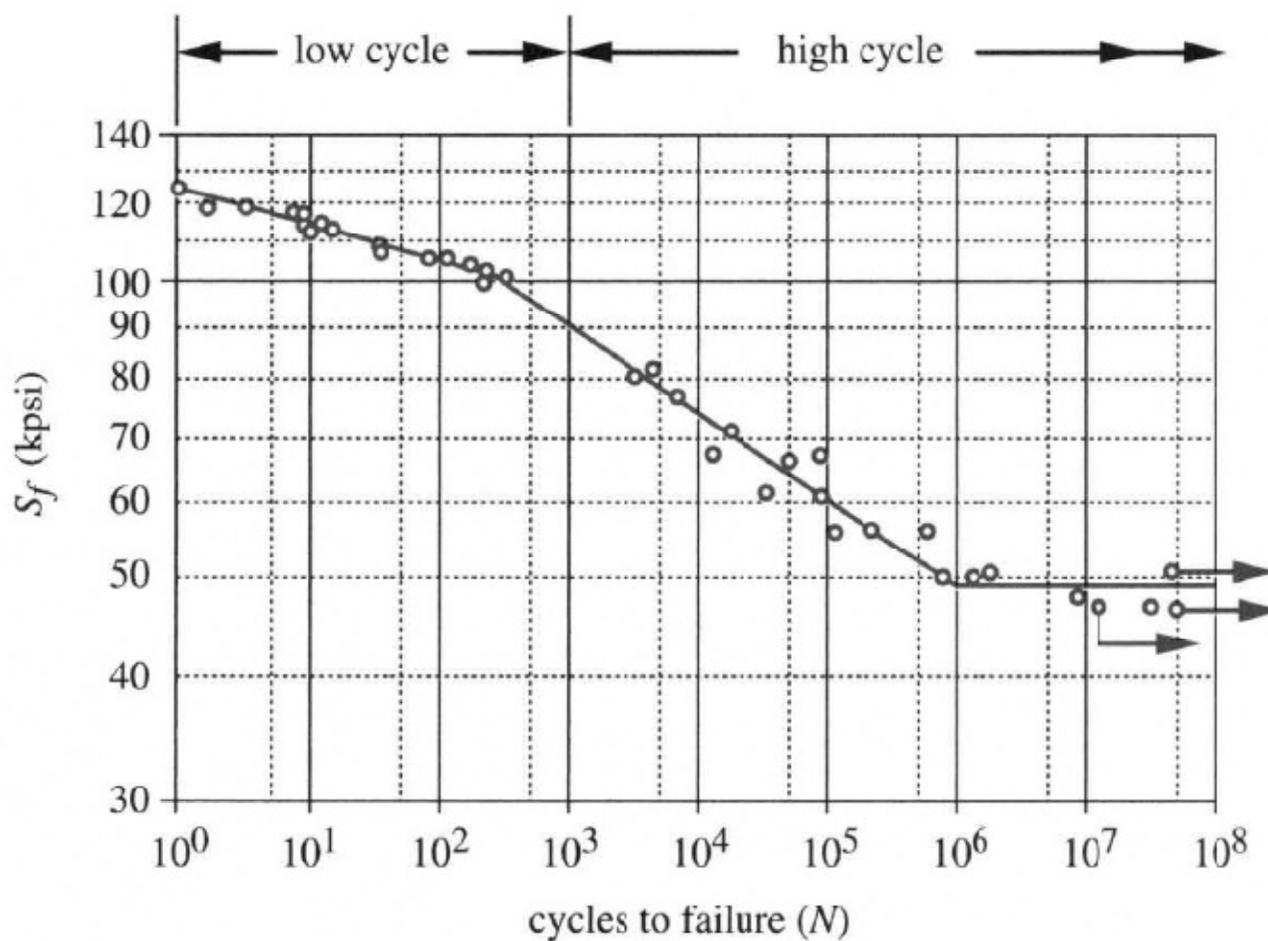
- Ensaio de fadiga sob força normal
- Ensaio de fadiga sob flexão
- Ensaio de fadiga sob torção



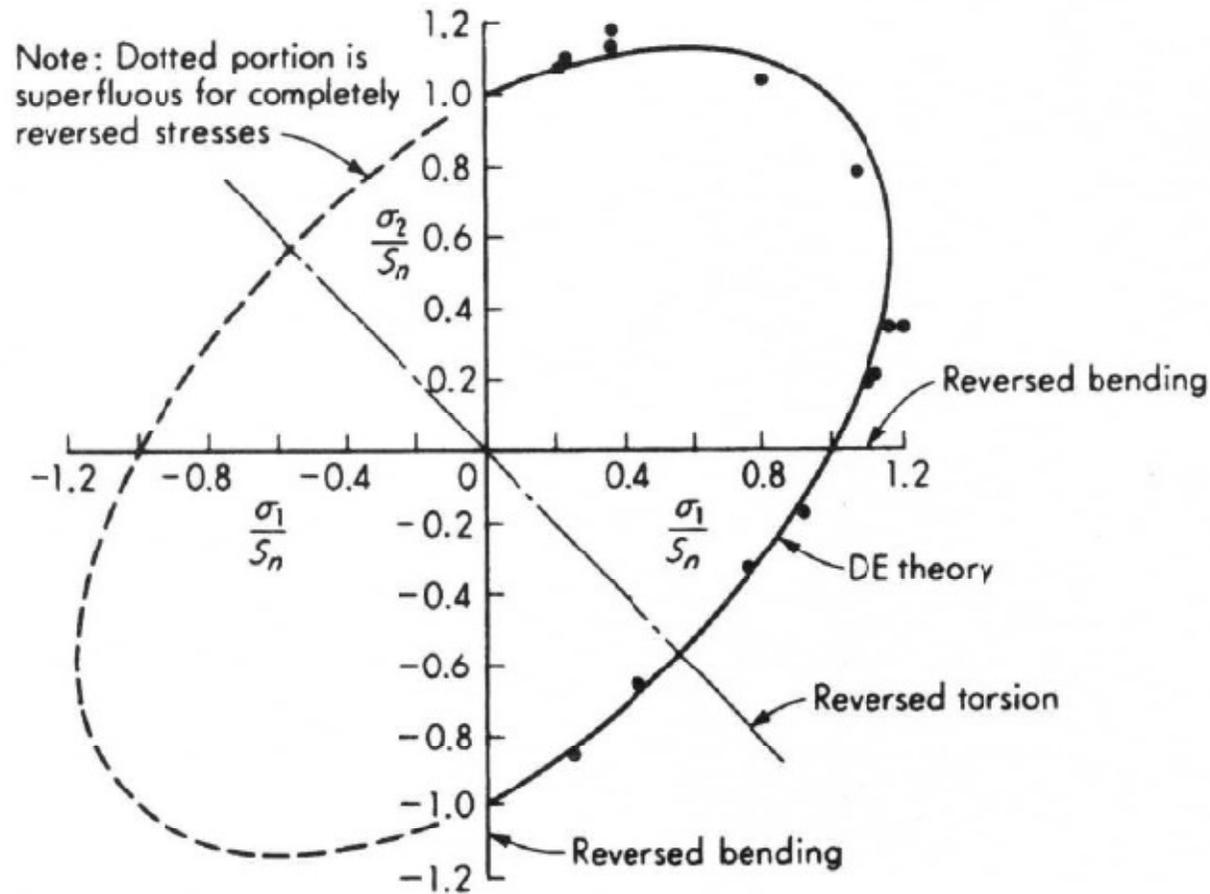


Curva S-N

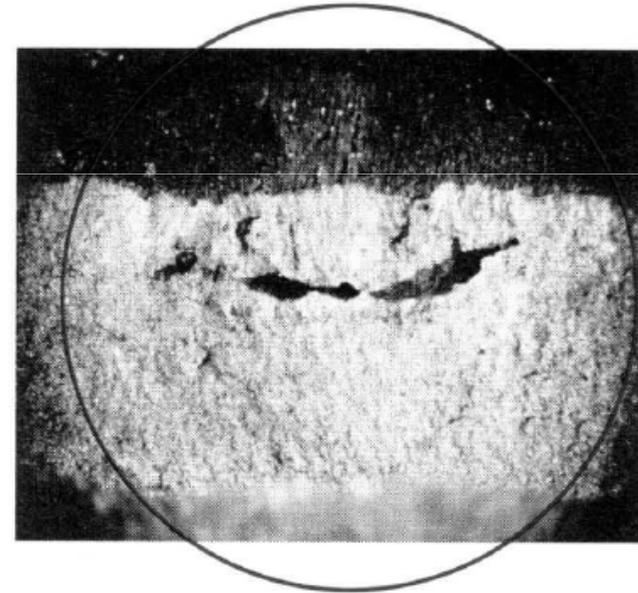
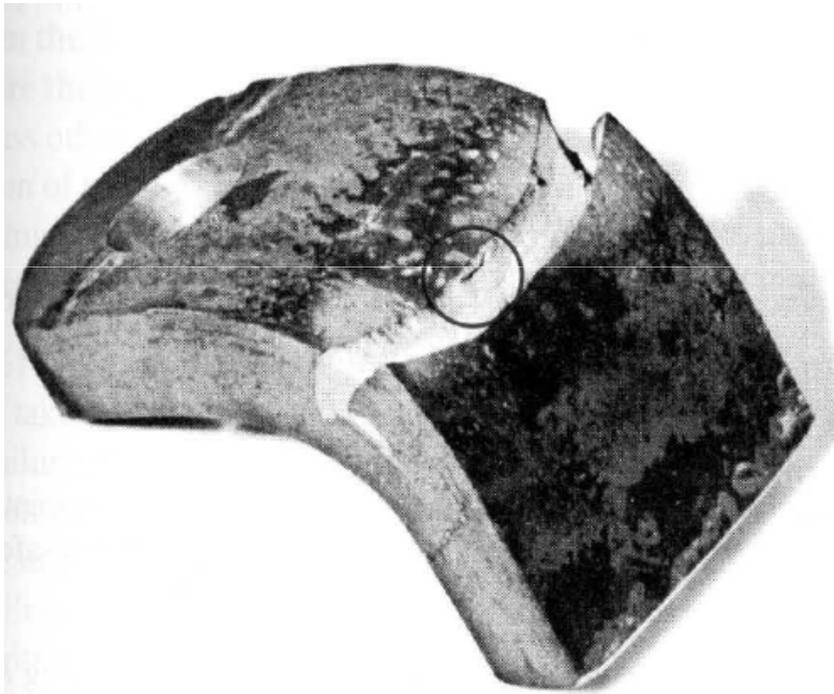
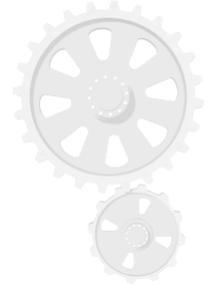
- Determinação dos pontos de inflexão



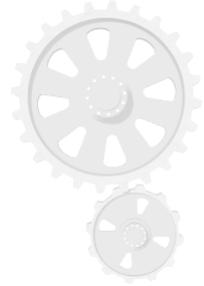
Dados do ensaio de fadiga plotados no diagrama $\sigma_1 \times \sigma_2$



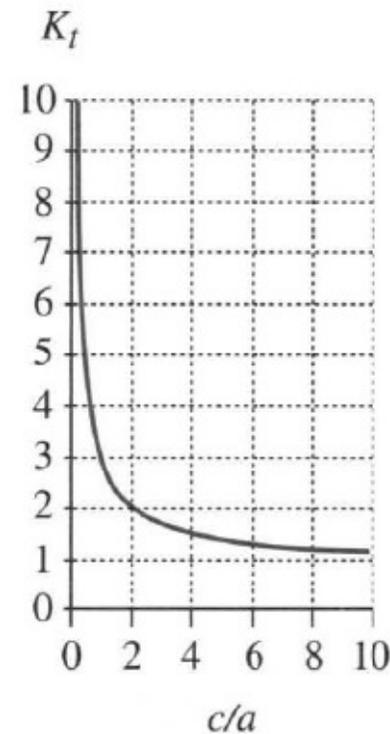
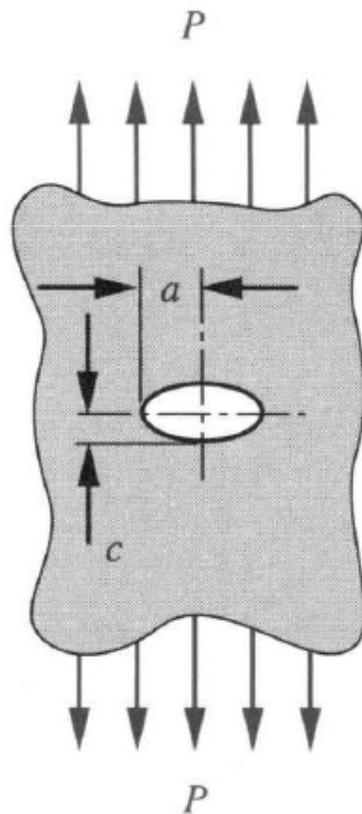
Mecânica da fratura



Mecânica da Fratura



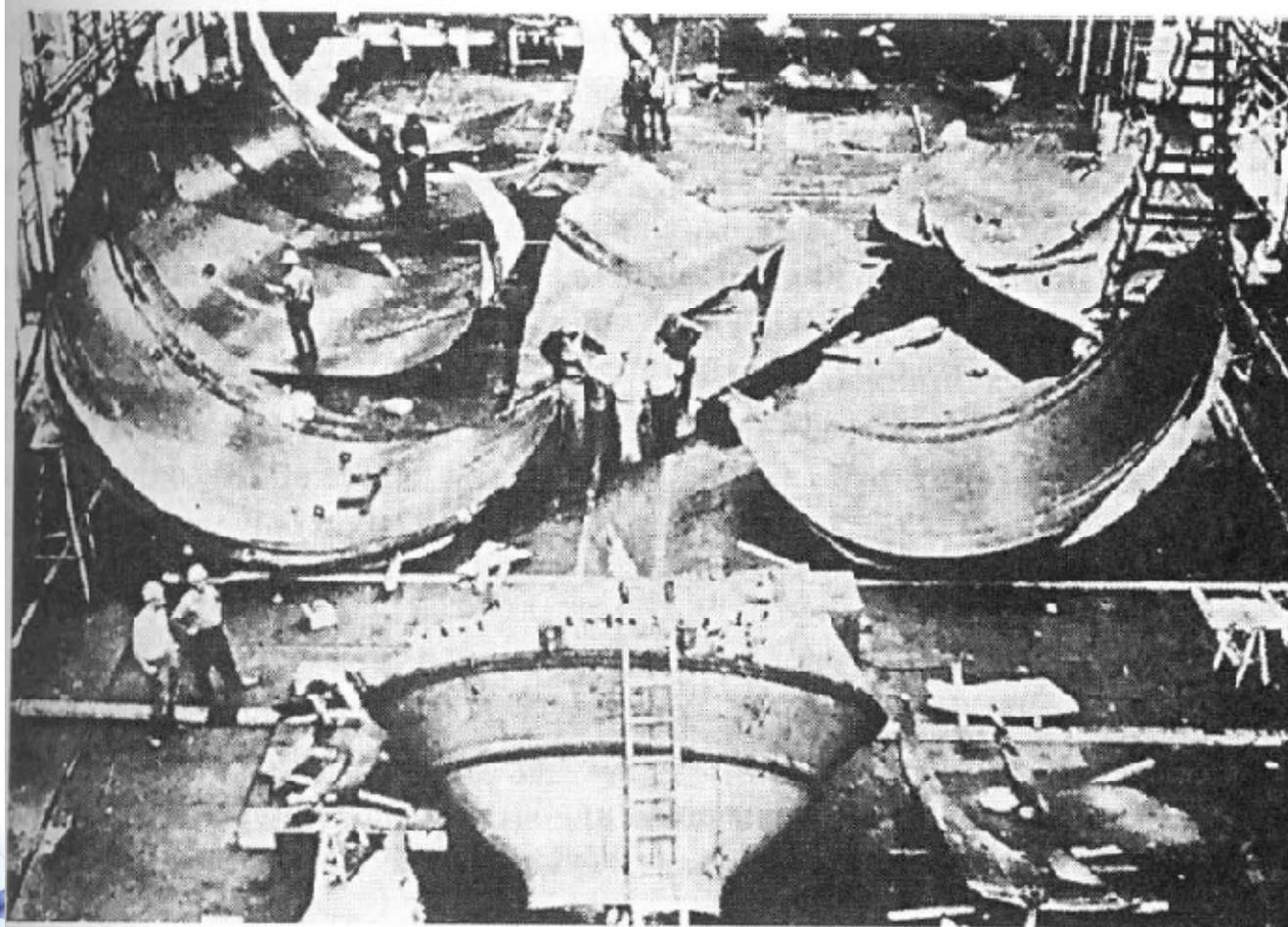
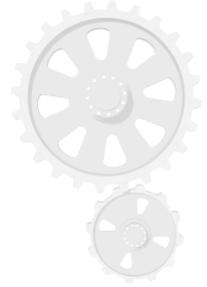
- Concentração de tensão criada por uma trinca



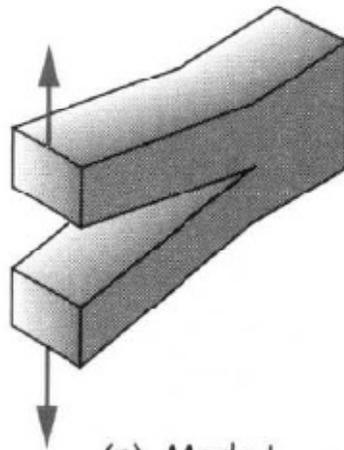
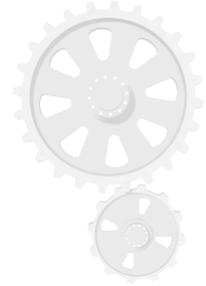
$$K_t = 1 + 2\left(\frac{a}{c}\right)$$



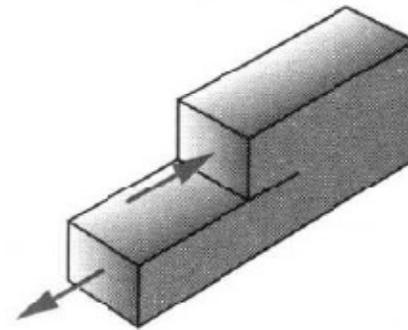
Exemplo



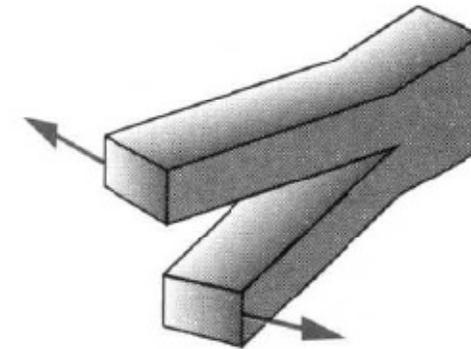
Modos geométricos da trinca



(a) Mode I



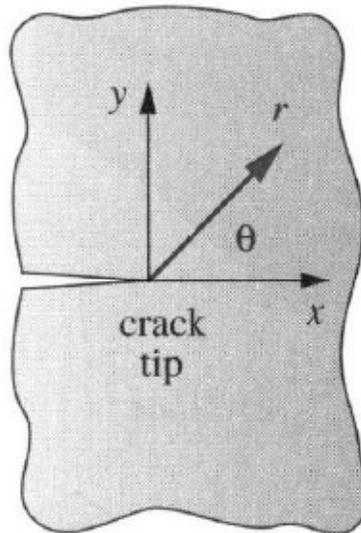
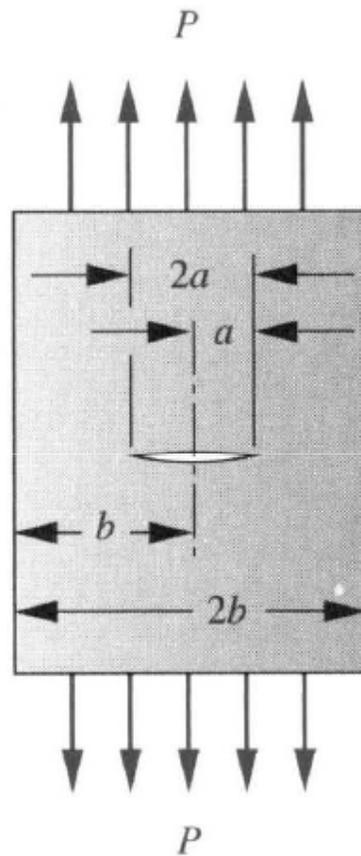
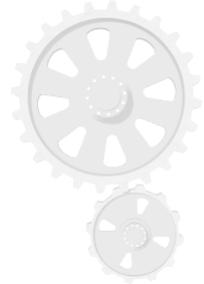
(b) Mode II



(c) Mode III



Fator de intensidade de tensão



$$\sigma_x = \frac{K}{\sqrt{2\pi r}} \cos \frac{\theta}{2} \left[1 - \sin \frac{\theta}{2} \sin \frac{3\theta}{2} \right] + \dots$$

$$\sigma_y = \frac{K}{\sqrt{2\pi r}} \cos \frac{\theta}{2} \left[1 + \sin \frac{\theta}{2} \sin \frac{3\theta}{2} \right] + \dots$$

$$\tau_{xy} = \frac{K}{\sqrt{2\pi r}} \sin \frac{\theta}{2} \cos \frac{\theta}{2} \cos \frac{3\theta}{2} + \dots$$

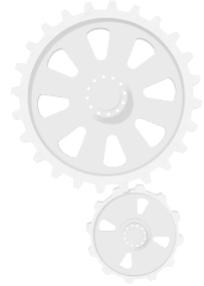
or $\sigma_z = 0$ for plane stress

$\sigma_z = \nu(\sigma_x + \sigma_y)$ for plane strain

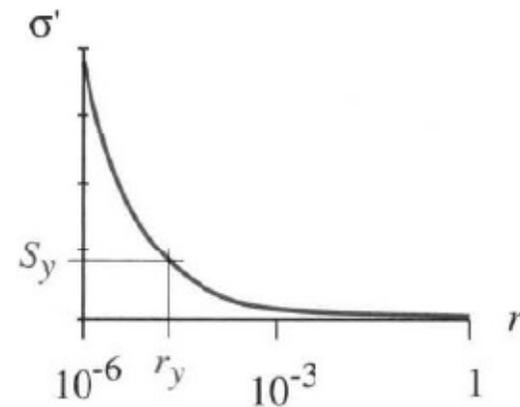
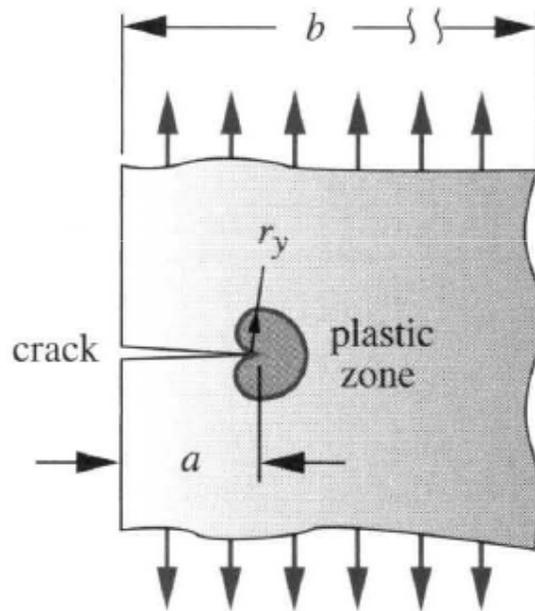
$\tau_{yz} = \tau_{zx} = 0$



Fator de intensidade de tensão

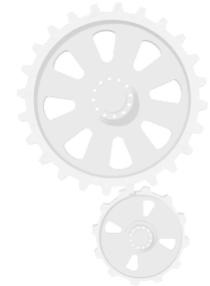


- Se $b \gg a$



$$K = \sigma_{nom} \sqrt{\pi a}$$





- Se a não é pequeno comparado a b e se a geometria da trinca não é simples:

$$K = \beta \sigma_{nom} \sqrt{\pi a}$$

β Pode assumir diversos valores que são tabelados. Em uma placa com uma trinca central o valor de β será por exemplo:

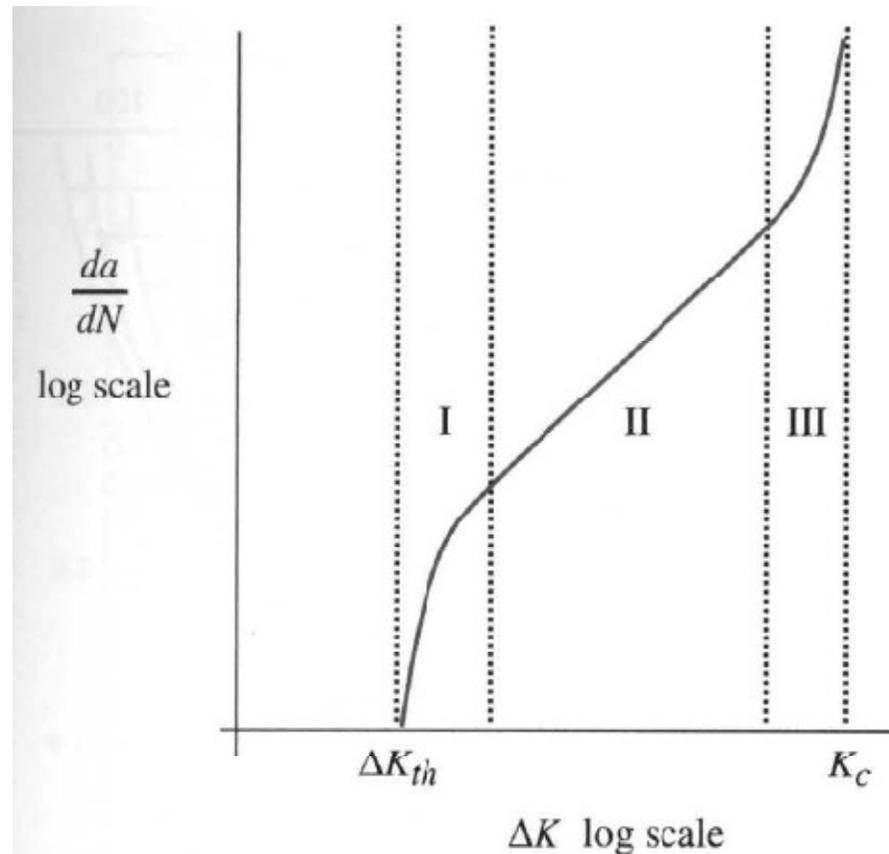
$$\beta = \sqrt{\sec\left(\frac{\pi a}{2b}\right)}$$



Critério da Mecânica da Fratura



$$\frac{da}{dN} = A(\Delta K)^n$$



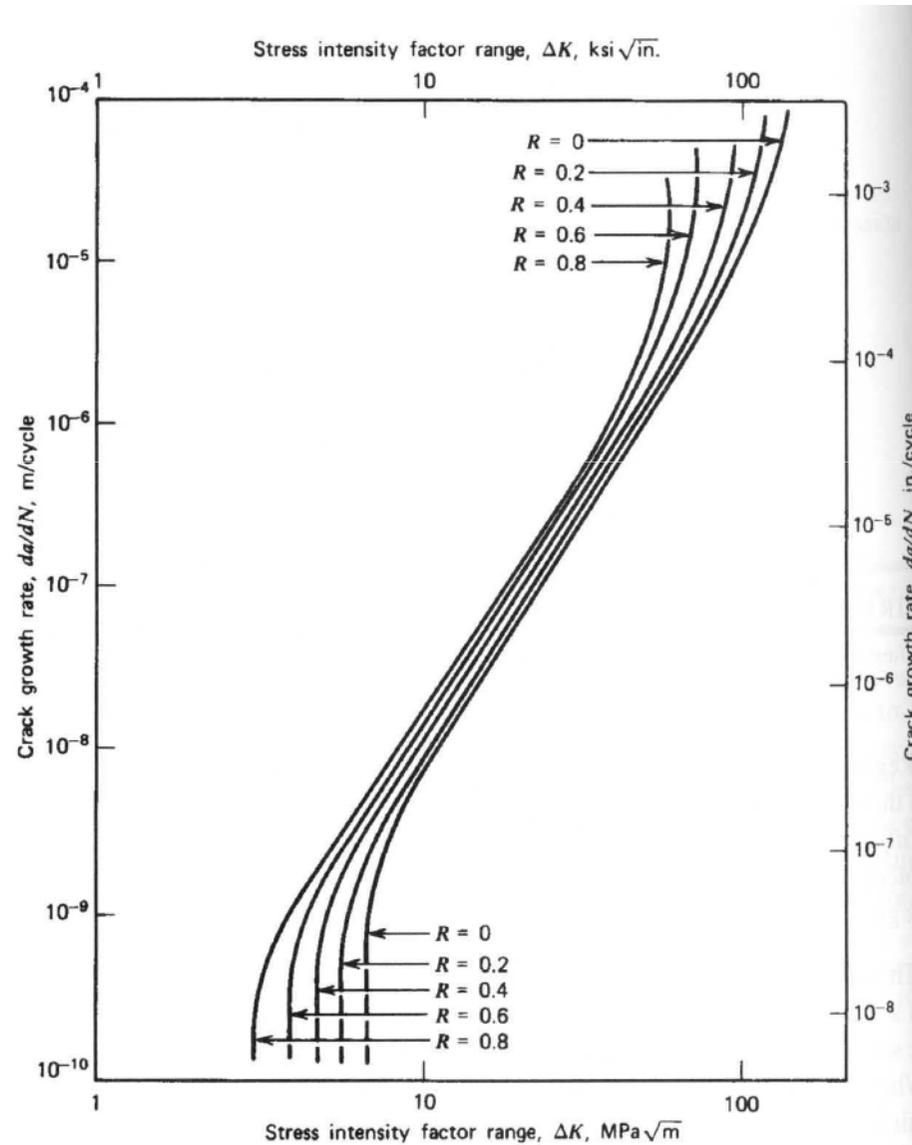
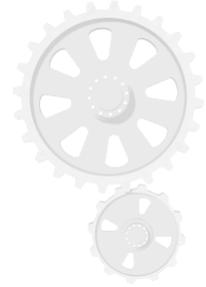
- I – início da trinca
- II – crescimento de trinca
- III – fratura instável

$$\Delta K = K_{max} - K_{min} : \quad \text{if } K_{min} < 0 \quad \text{then } \Delta K = K_{max}$$

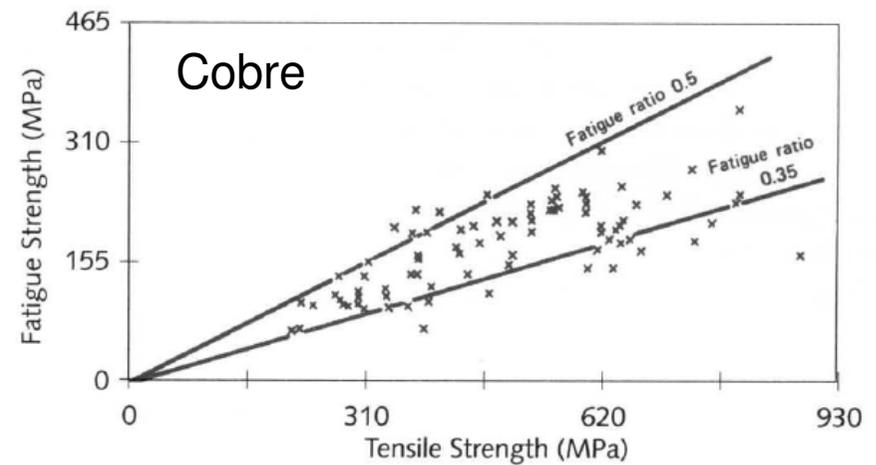
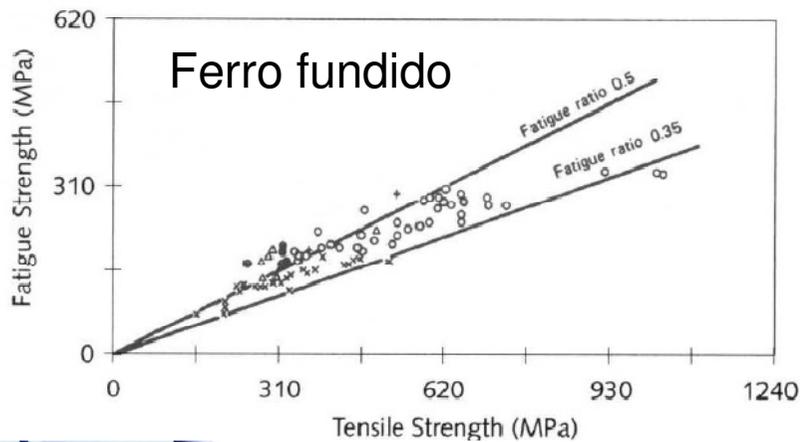
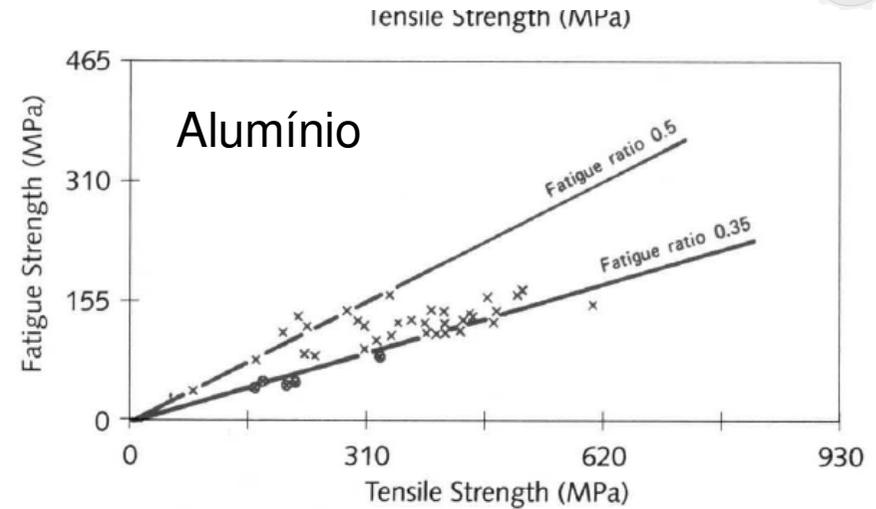
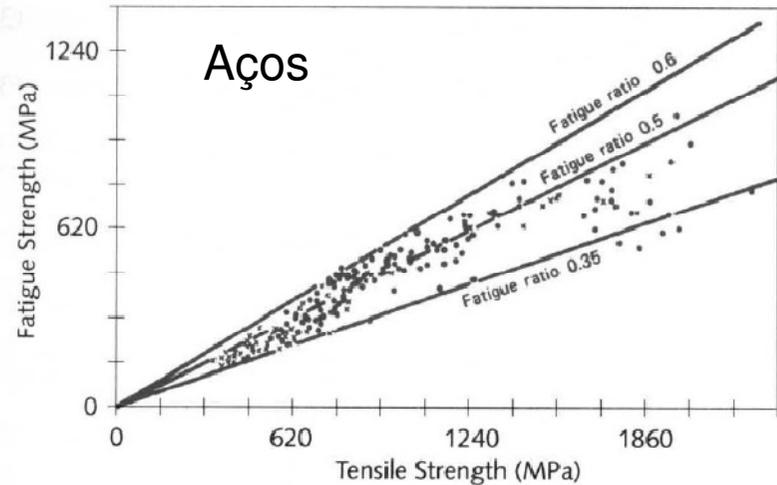
$$\begin{aligned} \Delta K &= \beta \sigma_{max} \sqrt{\pi a} - \beta \sigma_{min} \sqrt{\pi a} \\ &= \beta \sqrt{\pi a} (\sigma_{max} - \sigma_{min}) \end{aligned}$$



Curva de crescimento de trinca



Critérios para estimar falha por fadiga



Fatores de correção para a fadiga



$$S_e = C_{load} C_{size} C_{surf} C_{temp} C_{reliab} S_e'$$

$$S_f = C_{load} C_{size} C_{surf} C_{temp} C_{reliab} S_f'$$

- Efeito de carga:

bending : $C_{load} = 1$

axial loading : $C_{load} = 0.70$

- Efeito de Tamanho (cilindros):

for $d \leq 0.3$ in (8 mm) : $C_{size} = 1$

for $0.3 \text{ in} < d \leq 10 \text{ in}$: $C_{size} = 0.869d^{-0.097}$

for $8 \text{ mm} < d \leq 250 \text{ mm}$: $C_{size} = 1.189d^{-0.097}$

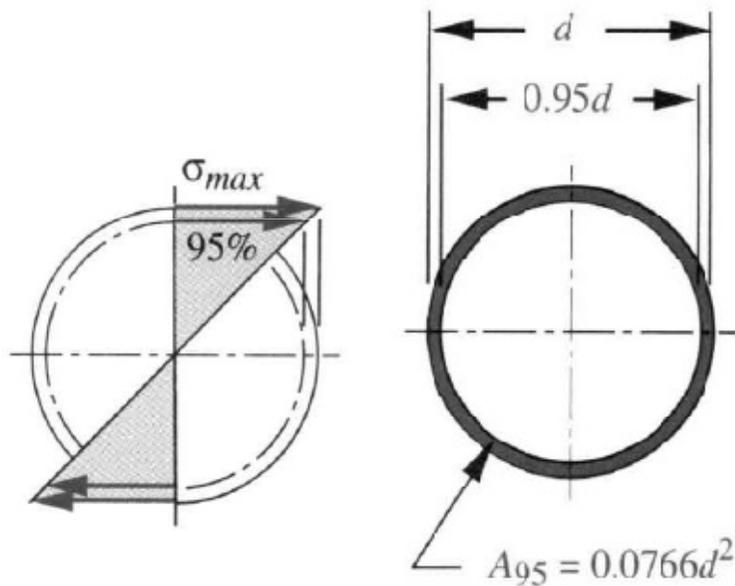
For larger sizes use $C_{size} = 0.6$.



Fatores de correção para a fadiga



- Efeito de tamanho para formas diversas:



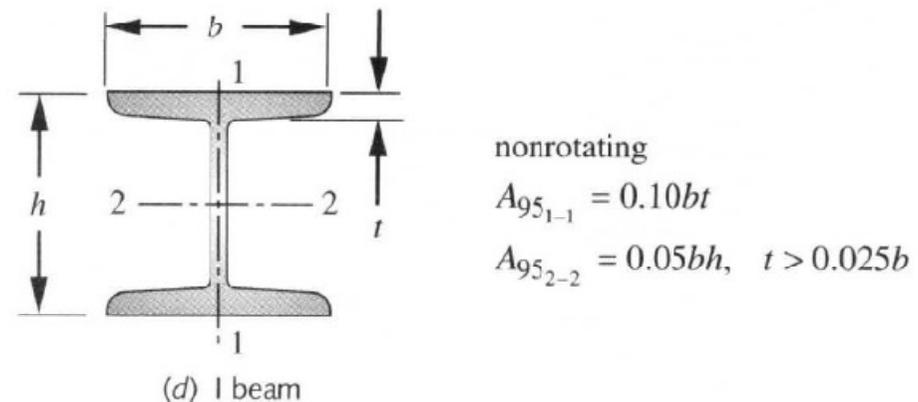
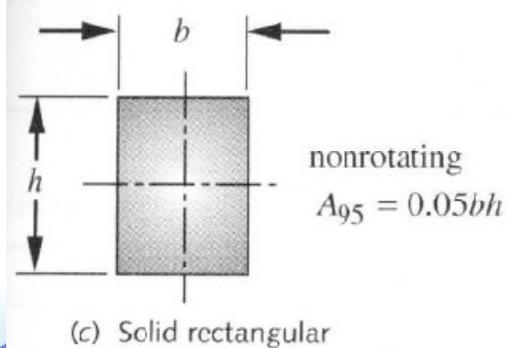
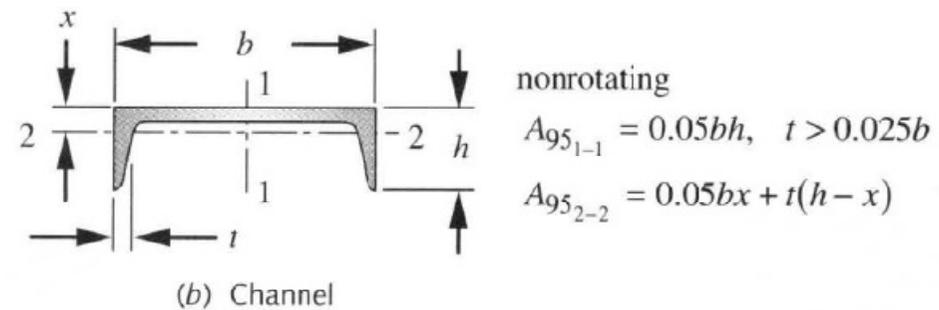
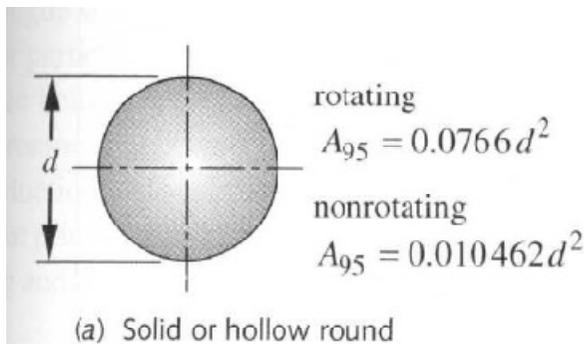
$$A_{95} = \pi \left[\frac{d^2 - (0.95d)^2}{4} \right] = 0.0766 d^2$$

$$d_{equiv} = \sqrt{\frac{A_{95}}{0.0766}}$$



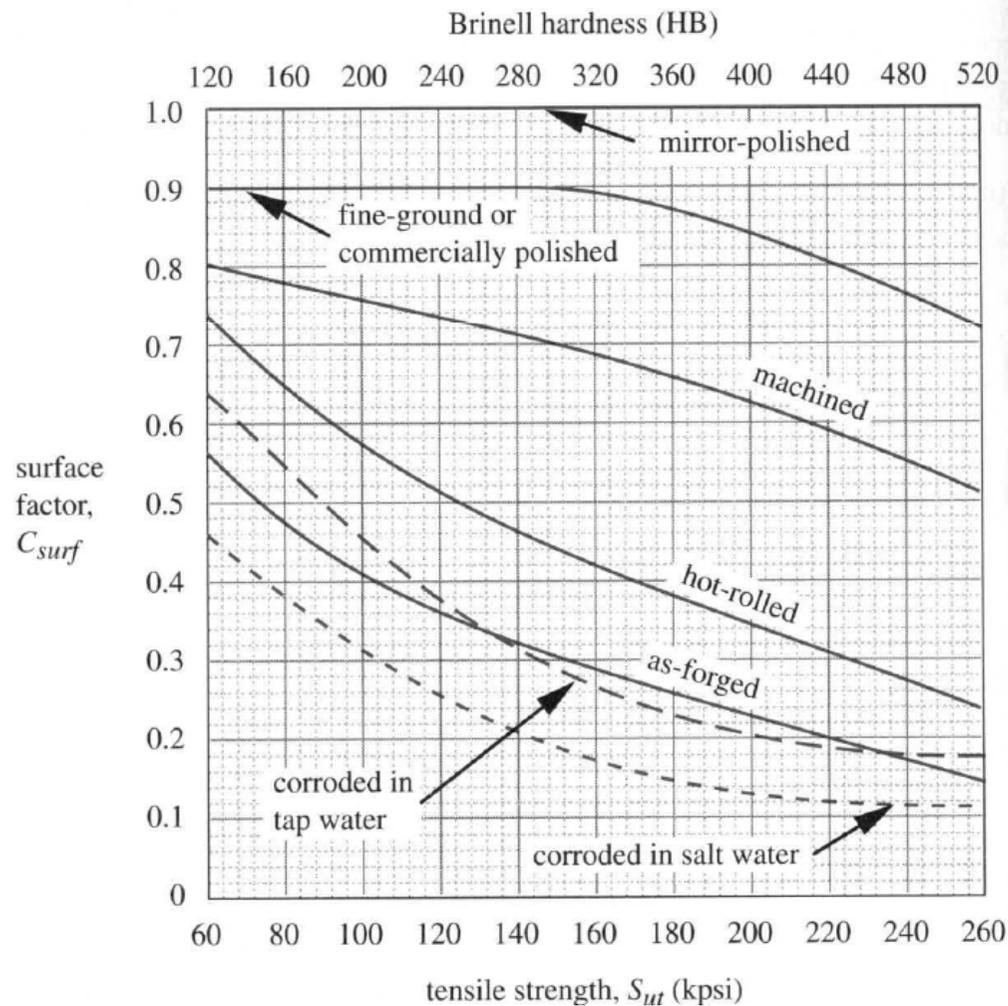
Fatores de correção para a fadiga

- Efeito de tamanho para formas diversas:



Fatores de correção para a fadiga

- Efeito de superfície:



Fatores de correção para a fadiga

- Efeito de superfície:

$$C_{surf} \equiv A(S_{ut})^b \quad \text{if } C_{surf} > 1.0, \text{ set } C_{surf} = 1.0$$

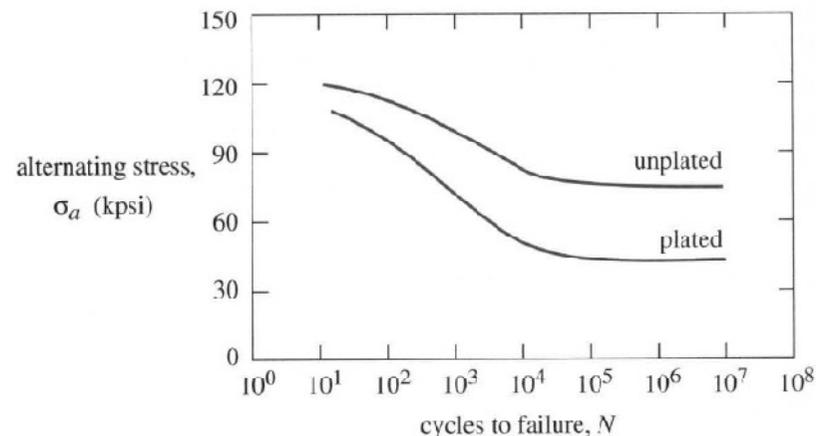
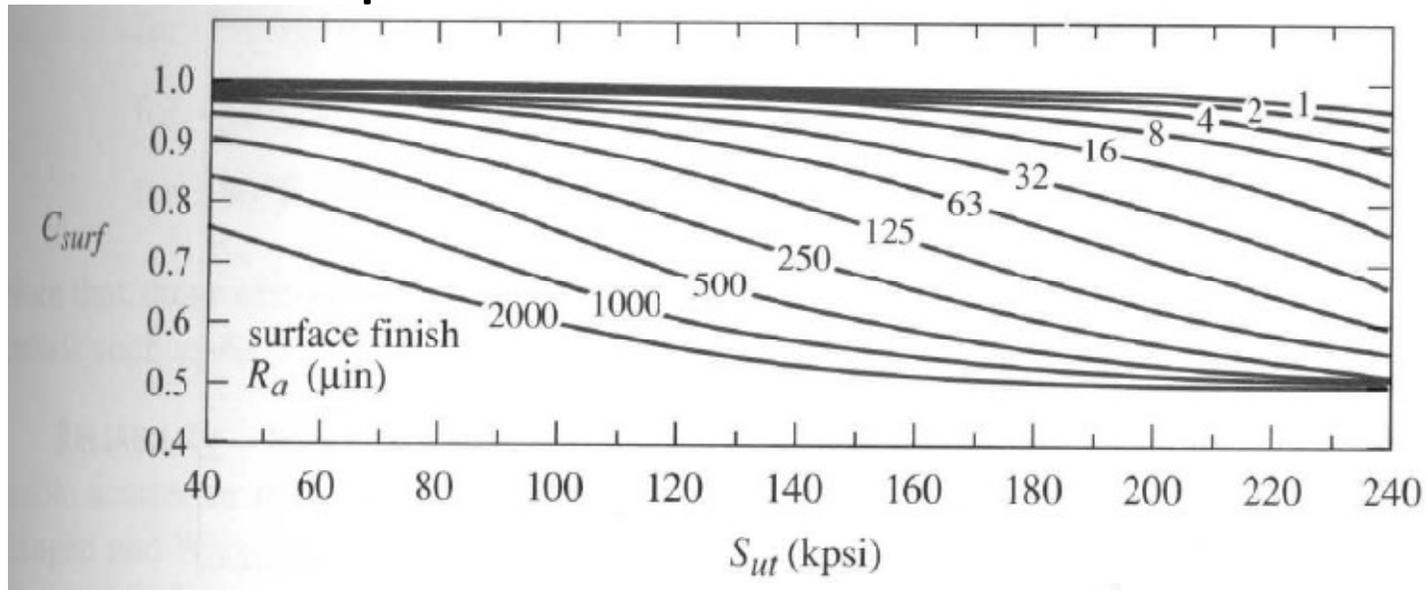
Surface Finish	For S_{ut} in MPa use		For S_{ut} in kpsi (<u>not psi</u>) use	
	A	b	A	b
Ground	1.58	-0.085	1.34	-0.085
Machined or cold-rolled	4.51	-0.265	2.7	-0.265
Hot-rolled	57.7	-0.718	14.4	-0.718
As-forged	272	-0.995	39.9	-0.995



Fatores de correção para a fadiga



- Efeito de superfície:



Fatores de correção para a fadiga



- Efeito de temperatura:

$$\text{for } T \leq 450^{\circ}\text{C (840}^{\circ}\text{F)}: \quad C_{temp} = 1$$

$$\text{for } 450^{\circ}\text{C} < T \leq 550^{\circ}\text{C}: \quad C_{temp} = 1 - 0.0058(T - 450)$$

$$\text{for } 840^{\circ}\text{F} < T \leq 1020^{\circ}\text{F}: \quad C_{temp} = 1 - 0.0032(T - 840)$$

- Efeito da confiabilidade

Reliability Factors
for $S_d = 0.08 \mu$

Reliability %	C_{reliab}
50	1.000
90	0.897
99	0.814
99.9	0.753
99.99	0.702
99.999	0.659



Fatores de correção para a fadiga



- Efeito de Ambiente:

